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Section 9

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9. Conceptual Site Model

9.1 General

Based upon the various data, analyses, and calculations presented throughout this report, this section presents a conceptual model for PCBs for the Rest of River. It discusses sediment transport within the system, followed by a summary of sources and sinks of PCBs, the major PCB fate and transport processes within the system, and a discussion of bioaccumulation. This section also discusses PCB temporal trends, and it concludes with a short summary regarding other constituents, notably PCDDs/PCDFs.

9.2 Sediment Transport

Watershed sediment loading to the River is relatively low (~15 to 30 MT/mi^2-yr) and consistent with a largely forested (71%) drainage area. The River channel is characterized as sinuous in Reach 5A and minimally to moderately meandering in Reaches 5B and 5C. Overall, the main channel appears to be relatively stable, with significant meandering occurring over timescales greater than 50 years. However, a few specific subreaches, which are relatively small compared to the entire reach, experience more active channel movement. Bank erosion occurs along a fraction of the channel shoreline in Reaches 5A and 5B and may produce significant sediment loads to the system, particularly during high-flow events.

Sediment transport in Reach 5A is dominated by suspended and bed load transport of non-cohesive sediment. The sediment bed in this reach appears to be in dynamic equilibrium (i.e., erosion and deposition approximately balance one another), with certain areas being net erosional and others net depositional. A percentage of the total sediment load entering Reach 5A from the East Branch is bed load. As the channel gradient decreases between the upstream and downstream limits of the reach, the sediment bed becomes finer and bed load transport decreases, with minimal (if any) bed load occurring at and downstream of New Lenox Road Bridge. Cohesive sediment transport becomes more important in Reach 5B, but the sediment bed is still primarily non-cohesive, although finer than that in Reach 5A because of the lower channel gradient. In most of Reach 5B, the channel is likely in dynamic equilibrium or depositional. Deposition is dominant in Reach 5C and Woods Pond, where most of the sediment bed is composed of cohesive sediment. The floodplain and backwaters are important during overbank floods, which occur almost annually. These areas act as sinks for suspended sediments because the presence of floodplain vegetation and submerged aquatic vegetation in the backwaters make these areas conducive to deposition.

Within Woods Pond and the nearby backwater regions, internal production enhances deposition. Significant growth of periphyton, phytoplankton, and macrophyte populations during the summer occurs in response to nutrient inputs from the WWTP; during the fall die-off period, a large fraction of the associated solids and organic matter is returned to the sediment bed where they are subject to decomposition. The depositional nature of Woods Pond is evidenced by the radioactive Cs-137 dating analyses, which indicate a net deposition rate of approximately 0.5 cm/yr in that impoundment. The deposition in Woods Pond and upstream backwaters is likely a combination of solids entering these reaches from upstream (i.e., Reaches 5A and 5B), growth of algae and macrophytes, and solids delivered by the tributaries (i.e., Roaring Brook and Yokun Brook).

Downstream of Woods Pond, the River is likely in a state of dynamic equilibrium in the free-flowing reaches. Additional solids inputs from tributaries cause the in-River suspended sediment loading to increase with downstream distance. The River is net depositional within the impoundments associated with the various dams in these reaches, as evidenced by radioactive Cs-137 dating analyses (e.g., about 1 cm/yr in Rising Pond).

The annual average sediment loads calculated for various locations along the River are plotted on Figure 9-1 to help to illustrate this conceptual model. Loads that originate from watershed and tributary inputs and in-channel erosion entering the Rest of River at Dawes/Pomeroy Avenue and the West Branch combine to a total of approximately 3700 MT per year. This value is similar to the load of 3200 MT per year at Holmes Road calculated from TSS concentrations measured at this location. Between the Confluence and New Lenox Road, the annual average sediment load increases to 4200 MT, which reflects the combined effects of tributary inputs (e.g., Sackett Brook) and net erosion of River sediments, and bank soils to some extent. Between New Lenox Road and Woods Pond Dam, the more quiescent environment associated with the decreased channel slope coincides with an approximate 60% decrease in the average suspended sediment load, indicating the net depositional character of the River in these reaches. The increase in average sediment load to 3800 MT downstream at Great Barrington indicates the additional inputs of solids from tributaries and the watershed over this 20 mile stretch of the River.

9.3 PCB Sources, Fate, and Transport

The only significant external PCB sources to the Rest of River are the inflows to the system at the Confluence. The existing water column data indicate that loads entering from the East Branch total approximately 10 kg/yr; most of this occurs at high flows, which is likely due to erosion of PCB-containing sediments and possibly bank soils along the reaches between the GE Plant area and the Confluence (see Section 8.6.1.1). An unmeasured quantity of PCBs associated with sediment bed load also enters the system from the East Branch; this contribution may be on the order of a few percent of the total load. These loads will likely decrease in the future in response to remediation efforts upstream of the Confluence. Estimated PCB loads entering from the West Branch are on the order of 2 kg/yr, but this value is uncertain due to less frequent monitoring and a high proportion of PCB concentrations below the detection limit.

The average estimated PCB loads are plotted on Figure 9-2 for stations representative of upstream loadings and of Reaches 5A, 5B, 5C, 6, and 8. These loads are shown separately for low-flow conditions (< 100 cfs at Coltsville) and higher-low conditions.. Under low-flow conditions, PCB loadings increase gradually, approximately tripling between the Confluence and Woods Pond Headwaters. This pattern is indicative of widespread diffusion of PCBs from surficial sediment pore waters, where PCBs desorb from sediment organic carbon under a state of equilibrium. On average, low-flow PCB loads decrease by approximately 20% across Woods Pond. This decrease is likely attributable to deposition within the Pond and sorption of dissolved PCBs to algae and periphyton associated with the macrophyte community, which are consequently sequestered within the Pond and returned to its sediments during the fall die-off period. The latter phenomenon enhances the net sediment deposition within these areas, and may serve as a mechanism to sequester PCBs within the surficial sediments. The backwater regions in the vicinity of Woods Pond likely experience little hydraulic exchange with the main channel under low flow, and are therefore likely characterized by higher water column PCB concentrations, which reflect a steady-state balance of diffusion flux from surface sediments and volatilization losses at the air-water interface. Low-flow PCB loading estimates (Figure 9-2) indicate a 20% decrease between Woods Pond and Division Street, which is likely caused by losses from volatilization and deposition that exceed PCB inputs associated with diffusion from surface sediments over this 20-mile stretch (although the higher proportion of non-detects at Division Street adds uncertainty to this loading estimate).

Loadings under higher-flow conditions (> 100 cfs at Coltsville) dominate PCB transport within the system, accounting for between 70% (Division Street) and 90% (Holmes and New Lenox Roads) of the total annual average load at these locations (Figure 9-2). The spatial changes in PCB loadings across the system reflect its sediment transport characteristics under these higher flows. PCB loads under these conditions increase by almost a factor of 4 between the Confluence and New Lenox Road, indicative of inputs from erosion of channel sediments and bank soils over this reach (i.e., Reach 5A and the upper portions of Reach 5B). A small fraction of the PCBs that are resuspended into the water column partitions to the dissolved phase. Substantial deposition of suspended solids and associated PCBs in Reach 5C and Woods Pond during these higher flows is evident in the net decrease in annual PCB loadings of 12% between New Lenox Road and the Headwaters and 43% across Woods Pond. Under high-flow conditions when the River overtops its banks, PCBs are also transported to the floodplains and backwaters in these reaches, where their deposition is enhanced by the submerged, emergent, and terrestrial vegetation in these areas. A net decrease in higher-flow PCB loading occurs between Woods Pond and Division Street; this trend is likely attributable to deposition within the various impoundments, as well as volatilization, which occurs at a greater rate under higher flows due to increased turbulence, especially in the fast-flowing stretches and over the dams located on the River over this reach.

On an annualized basis, internal PCB sources associated with sediments and bank soils exceed the loads entering the Rest of River, and are greatest in Reach 5A and the upper portion of Reach 5B (Figure 9-2). The flatter River gradient and lower-energy flow regime between Reach 5C and Woods Pond Dam promote the deposition of PCBs sorbed to sediments, some of which originated from within Reach 5A and the upper portion of Reach 5B. A portion of the PCB loads travel downstream of Woods Pond Dam, and decrease gradually due to deposition and volatilization.

This conceptual model of PCB fate is further illustrated by the spatial patterns in surface sediment data (one-mile reach averages) plotted on Figure 9-3 (repeated from Figure 4-12, above). Surface sediment PCB concentrations are relatively high in Reach 5A (i.e., the Confluence to RM 130), which is closest to the upstream source area, has been impacted by particulate PCB loadings (associated with suspended and bed loads), and is a region of active erosion during high flows. Low TOC concentrations in this reach are indicative of relatively coarse sediments and result in the highest organic carbon-normalized PCB concentrations, averaging approximately 10,000 mg/kg organic carbon. PCB concentrations in surface sediments are lower in Reach 5B (i.e., RM130 to RM128), which suggests the addition of clean solids from tributaries and internal biological production downstream of the WWTP. Surface sediment PCB concentrations increase across Reach 5C, and are highest in Woods Pond, averaging approximately 30 to 40 mg/kg. This increase is associated with the depositional nature of these reaches. The significantly higher organic carbon content of the sediments in Reach 5C and Woods Pond (i.e., averages in the range of 4% to 8%), which are associated with the fine-grained sediments in these areas coupled with the influence of algae and macrophyte production and decomposition, contribute to the higher PCB concentrations by providing a greater PCB sorption capacity. The organic carbon-normalized PCB concentrations in these reaches are more than an order of magnitude less than in Reach 5A, indicating that the higher dry-weight PCB concentrations can be explained, in part, by the higher organic carbon content. In other words, the flux of organic carbon to the Reach 5C and Woods Pond surface sediments results in lower organic carbon-normalized PCB concentrations (which, in turn, determine the uptake of PCBs by benthic organisms).

Surface sediment PCB concentrations downstream of Woods Pond decrease significantly, with typical averages of about 1 mg/kg. This decrease is related to the reduction in PCB transport caused by deposition in Reach 5C and Woods Pond and the progressive increase in clean solids flux to the River that serves to reduce PCB concentrations. Surface sediment PCB concentrations are slightly higher in Rising Pond, which is likely due to the depositional nature of that impoundment and the higher inventory of organic carbon associated with fine sediment accumulation in this impoundment. From Rising Pond to Connecticut, surface sediments PCBs average less than 1 mg/kg and organic carbon-normalized concentrations are variable, but in the range of 100 mg/kg organic carbon or less, which is approximately 100 times lower than concentrations in Reach 5A. The continual decrease in organic carbon-normalized PCBs evident on Figure 9-3 is consistent with increasing distance from the source area.

The PCB distribution within the floodplains further illustrates the fate and transport characteristics of the Rest of River. PCB concentrations in floodplain soils are highest within Reach 5, similar to the sediments. PCBs are higher in riverbank soils and decrease with lateral distance from the River channel, which reflects the lower frequency of inundation in the distal portions of the floodplain. This is demonstrated by the approximate five-fold decrease in average PCB concentrations between the 2-year and 2- to 10-year floodplains. PCBs are non-detect or considerably lower beyond the 10-year floodplain. PCB concentrations are higher in vernal pools, which is related to the significantly higher organic carbon content of these areas. The floodplain does not encompass a significant area in the vicinity of Woods Pond. Downstream of Woods Pond, floodplain PCB concentrations are significantly lower, which again is consistent with the sediment data and indicates that a majority of the PCB loads that originated upstream are sequestered within the sediments and floodplains of Reaches 5 and 6.

9.4 PCB Bioaccumulation

In general, concentrations of PCBs in the biota within Reaches 5 and 6 reflect a response to PCBs contained in the water column and surface sediments. Exposure to local sediment and water column sources promotes PCB partitioning into the lower trophic levels of the food chain: that is, to algae and macrophyte-associated periphyton and subsequently the benthic and water column invertebrate populations. PCBs are then transferred up the food chain to foraging fish (e.g., pumpkinseed, white sucker, and brown bullhead) feeding on invertebrates. PCBs bioaccumulate in predatory fish (e.g., largemouth bass) that feed on smaller fish. Bioconcentration, the net direct uptake from water through gill exchange, may contribute to fish body burdens, but to a lesser extent than these food web transfers. Growth dilution and excretion across the gut wall are the primary mechanisms by which PCB concentrations in fish tissue are reduced.

Spatial patterns of BAF and BSAF within Reaches 5 and 6 indicate that the dietary exposures for invertebrates and most fish species consist of a mixture of water column and sediment sources. Fish tissue PCBs originate from a mixture of sediment and water column sources, although this mixture appears to change from upstream to downstream and differs by species. In general, water column food sources appear to increase relative to sediment food sources from Reach 5A to Woods Pond. Data from Rising Pond suggest that PCB uptake of fish in this impoundment may be more linked to water column sources.

Overall, PCB concentrations in fish represent a mixture of exposure to water column and surface sediment PCB sources. Changes to exposure from these sources over time will therefore be reflected by the biota, although at different rates. Fish with a predominantly water-column based exposure route are likely to respond more rapidly to reductions in upstream PCB loads.

9.5 Temporal Trend Evaluation

Temporal trends in water column, surface sediments, and fish PCB concentrations were described in previous sections of this report. Considerable within-year variability, data limitations (e.g., limited sample numbers in 1980s data), and changes in sampling procedures (e.g., differences in fish tissue preparation) preclude drawing definitive conclusions regarding the significance of these trends. However, analyses of temporal trends in water column and surface sediment PCB concentrations in the Rest of River provide some evidence of a decline over the past 20 years (see Sections 3.7 and 4.6). The fish PCB data in Massachusetts are insufficient, either in sample size (for adult fish) or in length of time studied (for YOY fish), to make a temporal trend evaluation for fish in the Massachusetts portion of the River over a comparable period, although the PCB concentrations in the YOY data from 2002 are generally the lowest or among the lowest since that program began in 1994 (see Section 6.3.4.1). However, the fish data from Connecticut show a decline in PCB concentrations since the late 1970s (see Section 6.3.4.2).

To provide a further example, PCB trends in water and surface sediments in Woods Pond were evaluated together through temporal plots of annual average water column PCB loadings at Schweitzer Bridge and average 0- to-6 inch sediment PCB concentrations (Figure 9-4). While these values are not meant to be representative of the entire system, the plots demonstrate the interrelation of PCB concentrations in these media over time. These data exhibit considerable within-year variability, which makes it difficult to identify a significant temporal trend. However, the water and sediment data together suggest some decrease over the past 20 years within this reach. Average water column loads exiting Reach 6 in the late 1990s are approximately 40% lower than those from the early 1990s. Average surface sediment PCBs in the mid- to late-1990s are generally 30% to 50% lower than levels measured in the early 1980s. However, variability associated with small sample numbers in some years' datasets (e.g., 1991 and 1996) and differences in sampling locations (e.g., 2001 sampling targeted higher concentrations and was not meant to be representative of the entire Pond) add uncertainty to this interpretation. As discussed above, because of the depositional nature of this reach of the River, it would be expected that these media would respond to decreases in PCB loadings from upstream reaches.

The apparent decreasing trend in PCB concentrations may be associated with a response to the decrease in PCBs entering the Rest of River over the last 20 years. These decreases are likely associated with the various source control measures (e.g., groundwater and NAPL remediation) and in-River sediment removal actions (e.g., the Building 68 Area Removal Action) that have been implemented during this period. It is likely that this trend will continue as the completed sediment removal action in the Upper ½-Mile Reach and the ongoing sediment removal activities in the 1½-Mile Reach are expected to further decrease loads entering the system from the East Branch.

9.6 Other Constituents

As discussed in prior sections, various non-PCB constituents have been detected in the water, sediments, floodplain and riverbank soils, and biota in the Rest of River. However, based on EPA's screening evaluations for its risk assessments, these constituents, other than potentially PCDDs/PCDFs, are not considered constituents of concern for the Rest of River. With respect to PCDDs/PCDFs, the spatial distribution of these compounds in the sediments suggests that such constituents have entered the Rest of River from sources within the East Branch, with potential additional contributions from sources within the Rest of River. PCDD/PCDF concentrations within Reaches 5 and 6 indicate that these compounds have, to a large extent, accumulated within the fine sediments associated within Woods Pond. High concentrations of PCDDs/PCDFs are also observed in Rising Pond; these concentrations, together with composition differences between these PCDDs/PCDFs and those detected upstream, suggest that additional PCDD sources exist within Reaches 7 and/or 8. The fate and transport of these constituents is similar to that of PCBs, due to their similarity in physical-chemical properties.

Section 9 Figures

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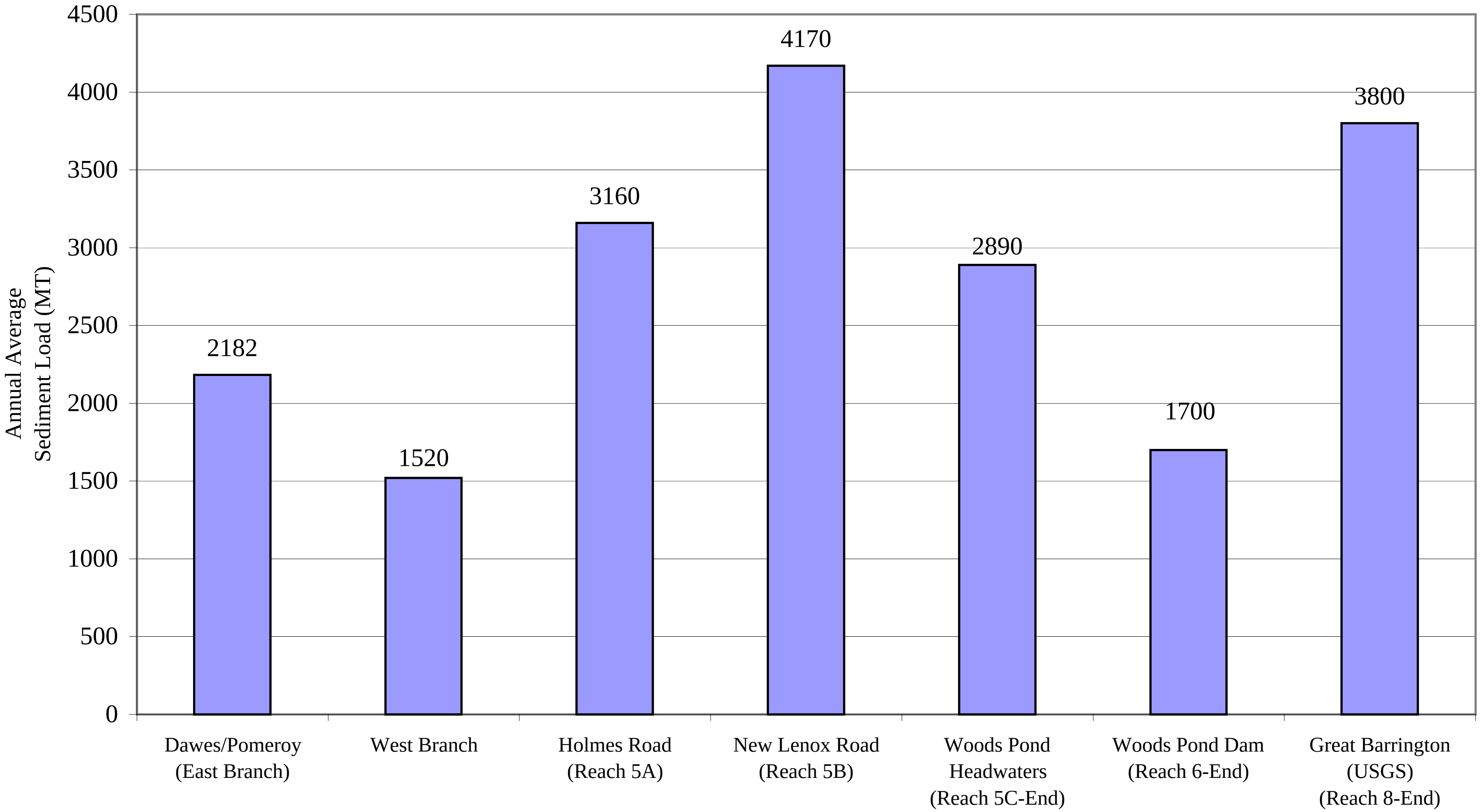

Figure 9-1. Summary of annual average sediment loadings at various locations along the Housatonic River.

Note: Great Barrington Estimate from USGS (2000).

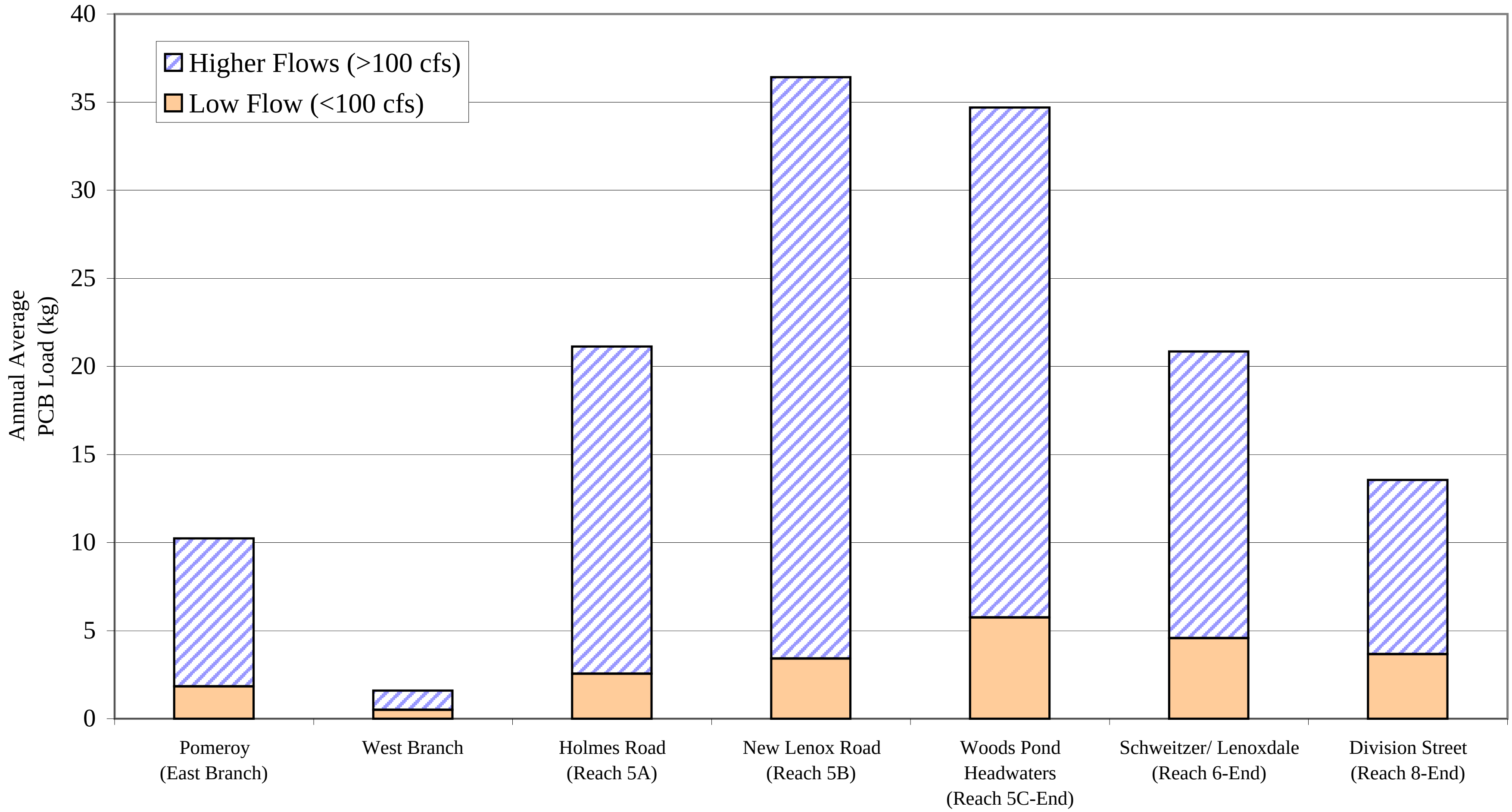

Figure 9-2. Summary of annual average PCB loadings at various locations along the Housatonic River.

Notes: Loads calculated using non-detects at 1/2 the MDL; high/low flow based on cutoff of 100 cfs at Coltsville.

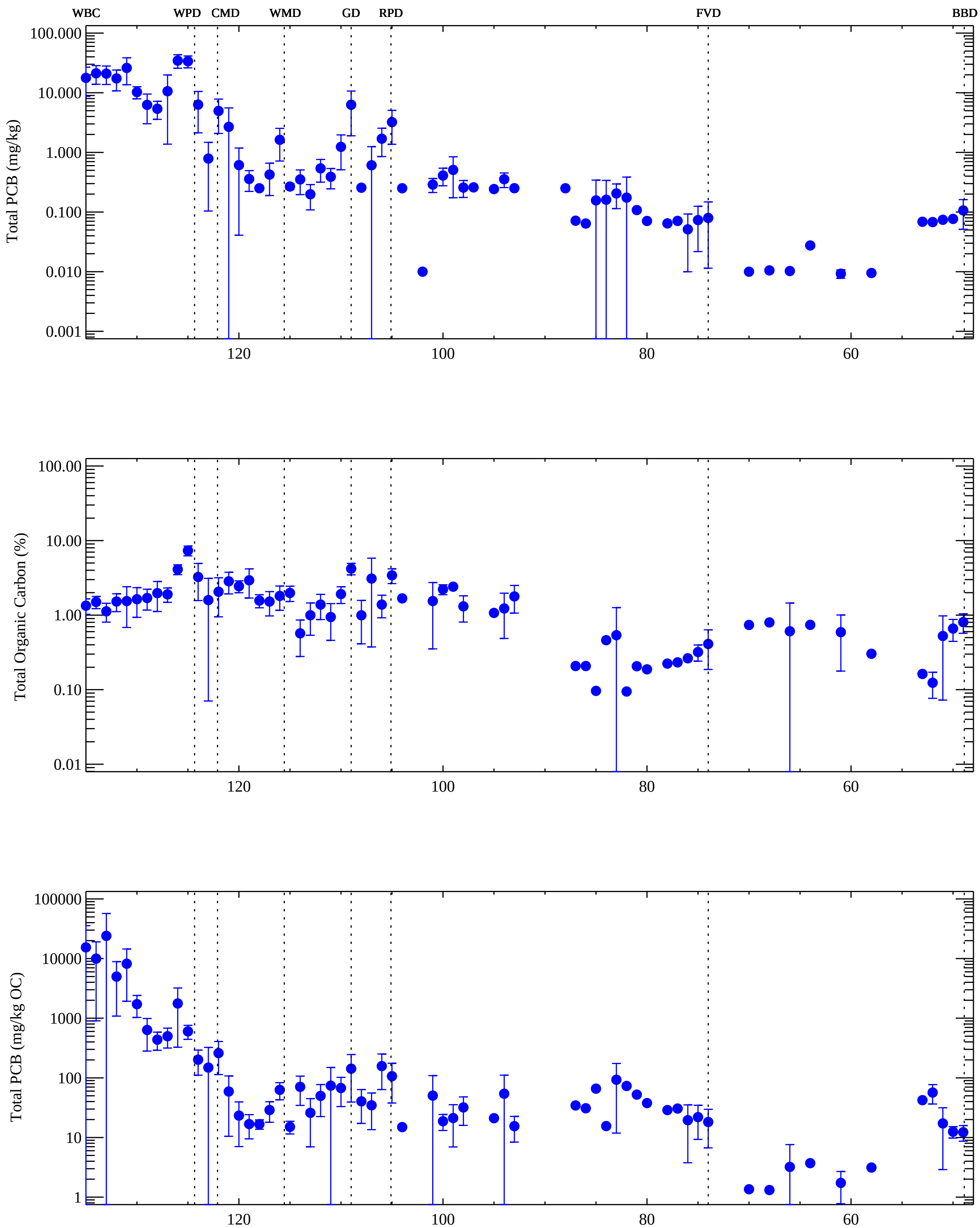

Figure 9-3. Spatial distribution of average PCB, TOC and organic carbon-normalized PCB in surface sediment.

Note: Data shown are 1998-2002 EPA and 1997-1998 GE data sets. Values shown are one-mile averages of the data. Error bars represent 2 standard errors of the mean.

Abbreviations: West Branch Confluence (WBC), Woods Pond Dam (WPD), Columbia Mill Dam (CMD), Willow Mill Dam (WMD), Glendale Dam (GD), Rising Pond Dam (RPD), Falls Village Dam (FVD), and Bulls Bridge Dam (BBD).

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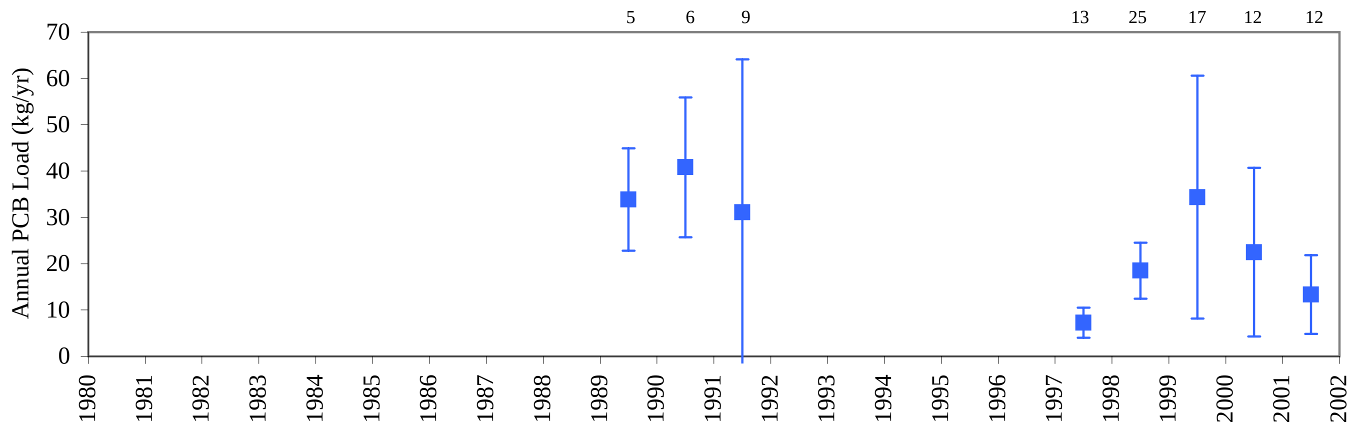
Water Column (Schweitzer/Lenoxdale)



Surface Sediments (0-6")

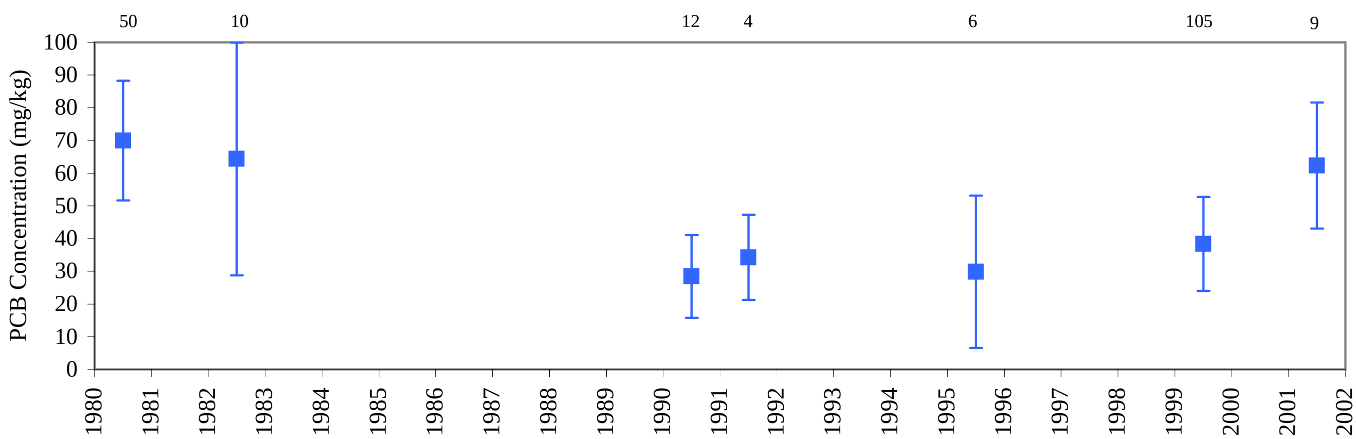


Figure 9-4. Temporal trends in water column and sediment PCB data collected in the vicinity of Woods Pond.

Notes: Numbers posted above data points represent the number of samples included in the average. Water column averages include GE/EPA routine monitoring data. Annual average high and low flow water column PCB loads were calculated and then weighted according to the percentage of high and low flow days within each year. Water column data from 1982 were omitted because data were insufficient to calculate an annual average.